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(54) **Hybrid optical IC with optical axes at different level.**

(57) There is disclosed an integrated optical device comprising:

a silicon substrate (1) having a surface;

a planar optical waveguide (20) which is formed partially on said silicon substrate (1), and has a light guiding core region (4) of high refractive index surrounded by a lower-index cladding layer (2,3) and a flat top surface;

a bonding pedestal (20a) which is formed partially on said silicon substrate occupying a portion different from the portion occupying said planar optical waveguide and has a flat top surface, the heights of said top flat surface of said bonding pedestal (20a) and said planar optical waveguide (20) from the surface of said silicon substrate being the same;

an edge input/output type optical semiconductor device (8) bonded on said top flat surface of said bonding pedestal (20a), said edge input/output type optical semiconductor device being mounted on an imaginary line extending from a light input/output end of said planar optical waveguide so that said edge input/output type optical semiconductor device align with said planar optical waveguide, levels of the optical axes of said planar optical waveguide and said edge input/output type optical semiconductor device from the surface of said silicon substrate

being different; and

means for changing level of an optical axis (10,11,12) for optically coupling said planar optical waveguide and said edge input/output type optical semiconductor device through changing height of optical axis relative to the surface of said silicon substrate.

There is also disclosed a manufacturing method for the device comprising the steps of:

forming an optical fiber guide groove and first and second lens guiding grooves for position-aligning lenses by selectively etching the surface of a silicon substrate through anisotropic etching;

bonding another silicon substrate having a planarizing layer formed on the surface of said other silicon substrate to said silicon substrate, by directing said cover layer to the surface of said silicon substrate;

removing said other silicon substrate and leaving said planarizing layer;

forming a deposited layer (20b) for planar optical waveguide by depositing lower cladding layer material and material for core region on said planarizing layer, by patterning said deposited materials for core region through photolithography and by depositing upper cladding layer material;

forming bonding pads (17) for bonding an optical

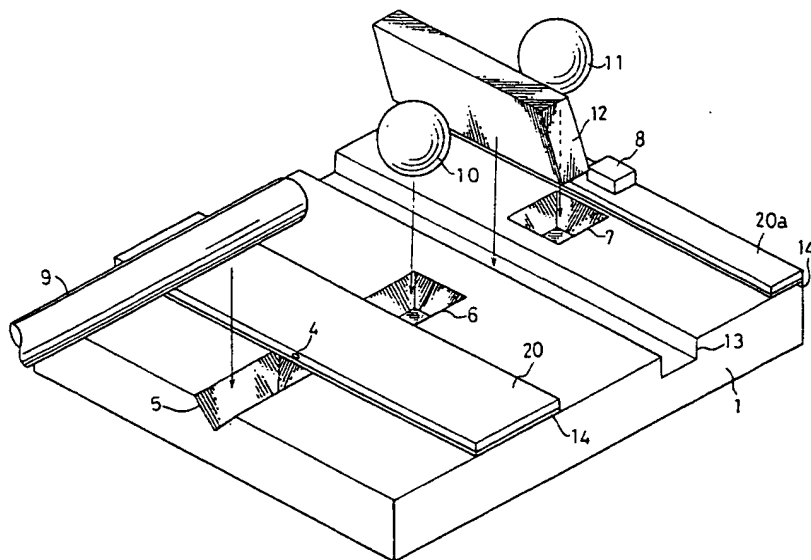
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semiconductor device (8) at a place corresponding to said bonding pedestal on said top surface of said deposited layer (20b) for planar optical waveguide;

selectively removing said optical waveguide and said planarizing layer and exposing said V groove and said first and second lens guiding grooves; and

forming a optical member guide groove (13) suitable for position-aligning a optical member (12) for shifting the levels of optical axes, on the surface of said silicon substrate between said first and second lens guiding grooves.

FIG. 1



## BACKGROUND OF THE INVENTION

### a) Field of the Invention

The present invention relates to an integrated optical device, and more particularly to a hybrid integrated optical device having optical fibers, optical waveguides, and optical semiconductor devices respectively integrated on a single substrate.

### b) Description of the Related Art

A conventional integrated optical device will be described with reference to Figs.9 to 13.

Fig.9 is a perspective view of a conventional optical IC disclosed in Japanese Patent Laid-open Publication No.57-84189. Semiconductor laser guides (recesses) 58 are formed on a substrate 51, and semiconductor lasers 57 are fitted in the semiconductor laser guides 58 and fixed thereto.

Laser beams emitted from the three semiconductor lasers are converged by a cylindrical lens 54 aligned in a lens guide groove 55 formed on the substrate 51, and guided to three light incident planes of an optical waveguide formed on the substrate 51. The optical waveguide 52 guide the three beams incident to the three light incident planes separately at first, and then multiplex or join them at the junction region thereof to output the laser beam from a single output plane thereof.

Along the optical axis of the outputted laser beam, a V groove 56 for guiding an optical fiber 53 is formed on the substrate 51, starting from the position corresponding to the light output plane to one end of the substrate 51. The optical fiber 53 is fitted in, and fixed to, the V groove 56.

The positions of the semiconductor lasers 57 and optical fiber 53 are therefore aligned by the semiconductor laser guides 58 and V groove 56 to provide optical coupling therebetween.

Figs.10A to 10F illustrate two different procedures of forming the optical fiber guiding V groove (hereinafter simply called a V groove) and the optical waveguide of the integrated optical device shown in Fig.9. In the procedure illustrated in Figs.10A to 10C, an optical waveguide is formed after a V groove has been formed.

As shown in Fig.10A, an SiO<sub>2</sub> film 62 is formed on the surface of a silicon substrate 61 having the (1 0 0) plane, and an opening 63 to be used for V groove etching is formed in the SiO<sub>2</sub> film 62 by photolithography. By using the SiO<sub>2</sub> film 62 as a mask, a V groove 64 is formed by anisotropic etching by using potassium hydroxide (KOH) aqueous solution, as shown in Fig.10A.

As shown in Fig.10B, a lower cladding layer 65 is formed on the whole surface of the SiO<sub>2</sub> film. Next, an core region 66 having a relatively high

refractive index is formed on the lower cladding layer 65 and patterned. An upper cladding layer 67 is then formed on the core region 66. As shown in Fig.10C, the lower cladding layer 65, core region 66, and upper cladding layer 67 are selectively etched to form an end plane of the optical waveguide. This end plane corresponds to light input/output port of the Planar waveguide.

The procedure illustrated in Figs.10D to 10F forms an optical waveguide before a V groove is formed. As shown in Fig.10D, a lower cladding layer 65, an optical waveguide core layer 66, and upper cladding layer 67 are formed on a silicon substrate 61 in the manner similar to the step of Fig.10D.

Next, as shown in Fig.10E, the lower cladding layer 65, core region 66, and upper cladding layer 67 are selectively etched to form an opening 68 to be used for V groove etching. As shown in Fig.10F, by using the optical waveguide components 65, 66, and 67 as a mask, the silicon substrate 61 is anisotropically etched to form a V groove 64.

With the method of forming an optical waveguide after a V groove has been formed, materials of the optical waveguide components are also deposited on the V groove 64 while the optical waveguide is formed. It is difficult to remove such materials on the V groove while maintaining the designed configurations of the V groove and optical waveguide, because the V groove is as deep as 100 μm usually.

With the method of forming an optical waveguide before a V groove is formed, the optical waveguide films 65, 66, and 67 are side-etched when the V groove etching opening 68 is formed, because the optical waveguide is thick. It is therefore difficult to form the V groove 64 precisely.

Further, the semiconductor laser 57 is fitted in the semiconductor laser guide 58 and bonded thereto in a junction-up position (with a heterojunction located upside). However, allowance of the height of the active region of a semiconductor laser is above  $\pm 10 \mu$  so that it is difficult to make the core region of a waveguide flush with the active layer.

Furthermore, the width of a semiconductor laser chip and the relative positions of the active region from its opposite side ends have a dimension allowance of above  $\pm 10 \mu$ . Therefore, the position displacement, less than  $\pm 3 \mu\text{m}$  is usually required for single-mode waveguide, is large if simply a semiconductor laser is fitted in the semiconductor laser guide 58, so that it is difficult to obtain sufficient coupling with an optical waveguide.

Still further, in forming bonding pads on the bottom of the semiconductor laser guide 58 by photolithography for bonding the semiconductor laser 57 thereto, the exposed image of a pattern has

blurred edges because of the steps of the optical waveguide and the laser guide groove, so that it is difficult to provide precise position alignment. More still further, the V groove 56, which is very deep for photolithographic process, prevents fine work.

Fig.11 shows an example of an integrated optical device disclosed in Japanese Patent Laid-open Publication No.61-46911. As shown, an optical fiber guide 72, an optical waveguide 73, and semiconductor laser guides 74 are formed on a substrate 71.

A semiconductor laser 75 having an active region 75a and a photodetector 76 are aligned with the semiconductor laser guides 74 and fixed thereto.

In the example shown in Fig.11, if usual optical fiber having a clad diameter of 125  $\mu\text{m}$  is used, it is necessary to set the height of the center of the core of the optical waveguide to 62.5  $\mu\text{m}$ , and the height of the optical fiber guide 72 becomes obviously higher than 62.5  $\mu\text{m}$ .

Therefore, if an  $\text{SiO}_2$  optical waveguide of high reliability is to be formed, it takes a long time to deposit the optical waveguide materials and etch and pattern the optical waveguide structure and guide structure.

Like the example shown in Fig.9, the dimension allowance of the height of the active layer of a semiconductor laser and the positions of active region from its opposite side ends is above  $\pm 10 \mu$ , so that it is difficult to make the active region 75a of the semiconductor laser 75 flush with the core region of the optical waveguide 73. The position alignment is particularly difficult if a single mode fiber and a single mode optical waveguide, which usually requires accurate positioning less than  $\pm 3 \mu\text{m}$ , are used.

Fig.12 shows an example of an integrated optical device disclosed in Japanese Patent Laid-open Publication No.2-58005. As shown, an optical waveguide 87, and bonding pads 81, 82, and 83 are formed on a substrate 80.

A bonding pad 82 is formed on the bottom of a semiconductor laser 84 and bonded to the bonding pad 82 on the substrate 80. In this case, the semiconductor laser 84 can be position-aligned precisely because if there is any misalignment, the bonding pad 86 makes a short circuit between the bonding pad 82 and the bonding pad 81 or 83.

However, a fine pattern of the bonding pads 81, 82, and 83 is difficult to be formed by photolithography because there is a step of the optical waveguide 87. It is therefore difficult to precisely align the active layer 85 of the semiconductor laser 84 with the core of the optical waveguide 87.

As described above, precise optical coupling between a semiconductor laser and an optical waveguide or between an optical waveguide and an

optical fiber is difficult because the pattern formed by photolithography has blurred edges because of steps of the optical waveguide and the like or because of the dimension allowance of the active layer of the semiconductor laser.

If materials of an optical waveguide enters a V groove, it is difficult to remove such materials while maintaining the designed configuration of the V groove.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide an integrated optical device and its manufacturing method capable of position-aligning optical fibers, optical waveguides, and optical semiconductor devices, easily and precisely.

According to one aspect of the present invention, there is provided an integrated optical device having: a silicon substrate; a planar optical waveguide which is formed partially on the surface of the silicon substrate, and has a light guiding core region of high refractive index surrounded by a lower-index cladding layer and a flat top surface; a bonding pedestal which is formed partially on the surface of the silicon substrate occupying a portion different from the portion occupying the planar optical waveguide and has a flat top surface, the height of the flat top surface of the bonding pedestal and the planar optical waveguide from the surface of the silicon substrate being the same; V groove having a V-character shaped cross section for position-aligning an optical fiber so as to optically couple the planar optical waveguide and the optical fiber, the V groove being formed on the surface of the silicon substrate along an optical axis extending in one direction from one light input/output port of the optical waveguide; an edge input/output type optical semiconductor device bonded on the top surface of said bonding pedestal, the optical semiconductor device being mounted on a line extending from the other light input/output port of the optical waveguide along the optical axis; and optical axis level changing means for optically coupling the optical waveguide and the optical semiconductor device by changing the heights of optical axes relative to the surface of the silicon substrate at both the active region of the optical semiconductor device and the core region of the planar optical waveguide.

Preferably, the optical axis level changing means includes: a first lens for collimating a light beam emitted from the optical semiconductor device or converging a collimated light beam into the optical semiconductor device; a first lens guide hole formed on the surface of the silicon substrate for position-aligning the first lens on the surface of the silicon substrate; a second lens for converging

a collimated light beam into the optical waveguide or collimating a light beam emitted from the optical waveguide; and a second lens guide hole formed on the surface of the silicon substrate for position-aligning the second lens on the surface of the silicon substrate; an optical member for refracting a light beam to change the heights of the optical axes, the optical member being provided between the first and second lenses; and an optical member guide groove formed on the surface of the silicon substrate for position-aligning the optical member on the surface of the silicon substrate.

The optical member may include a transparent plate made of a material transparent relative to the wavelength of a transmission light beam, the light incident and output planes of the transparent plate being disposed to be inclined by a predetermined angle from an optical axis of incident ray.

The optical member may include a transparent plate having both opposite planes disposed to be inclined by a predetermined angle from an optical axis, and two support members having one planes disposed perpendicular to an optical axis, and the other planes disposed in tight contact with the light incident and output planes of the transparent plate, the two support members each being formed with a through hole at the region where a light beam transmits.

According to another aspect of the present invention, there is provided a method of forming an integrated optical device including the steps of: forming a V groove and first and second lens guiding grooves for position-aligning lenses by selectively etching the surface of a silicon substrate through anisotropic etching; bonding another silicon substrate having an SiO<sub>2</sub> film formed on the surface of the other silicon substrate to the silicon substrate, by directing the SiO<sub>2</sub> film to the surface of the silicon substrate; removing the other silicon substrate and leaving the SiO<sub>2</sub> film for a planarizing layer; forming a deposited layer for optical waveguide by depositing cladding layer material and core material of core region on the SiO<sub>2</sub> film, by patterning the layer for core region through photolithography; and by depositing upper cladding layer material so as to planarize the top surface of the planar waveguide and cover the core region; forming bonding pads for bonding an optical semiconductor device at the place which corresponds to the bonding pedestal on the top surface of the deposited layer for the planar waveguide; selectively etching the deposited layers for optical waveguide and the SiO<sub>2</sub> film, forming waveguide and light input/output ports, bonding pedestal and exposing the V groove and the first and second lens guiding grooves; and forming an optical member guide groove suitable for position-aligning an optical member for shifting the levels of

optical axes, on the surface of the silicon substrate between the first and second lens guiding grooves.

Bonding pads for bonding an optical semiconductor device can be formed on a flat, top surface of the deposited layers for optical waveguide so that patterns can be formed at high precision. If an optical semiconductor device is flip-chip bonded, the active region of the optical semiconductor device can be positioned at high precision irrespective of its outer dimension.

An optical axis can be shifted by disposing an optical member to be inclined relative to the optical axis of incident light beam. It is therefore possible to optically couple the optical waveguide and the active region of the optical semiconductor device both having different heights from the substrate surface.

The optical member may be of a three-layer structure made of transparent optical members having different refractive indices. By inclining the interfaces between the three layers, it is possible to dispose the light incident and output planes perpendicularly to the optical axis. It is therefore possible to improve the position alignment precision of the optical member.

Birefringence material may be used for the optical member to allow the light incident and output planes to be disposed perpendicularly to the optical axis, to thereby improve the position alignment precision of the optical member.

By covering the openings of the V grooves for positioning an optical fiber and other grooves with an SiO<sub>2</sub> film / or a silicon layer, it is possible to prevent the materials of an optical waveguide from being entered into the grooves when the planar optical waveguide is formed.

If a thick silicon layer is used to cover the V groove for optical fiber guide and other grooves, the core region of an optical waveguide can be made much higher than the surface of the substrate. Accordingly, the diameter of a laser beam can be made larger to thus improve the optical coupling tolerance.

As described above, an optical semiconductor device such as a semiconductor laser and an optical fiber can be optically coupled with highly precise position alignment without any adjustment. It is therefore possible to easily manufacture a hybrid optical transceiver widely used by optical communications.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a perspective view of an integrated optical device according to a first embodiment of the present invention.

Figs.2A and 2B are cross sectional views of the integrated optical device of the first embodiment.

Figs.3A to 3J are cross sectional views explaining a method of manufacturing an integrated optical device according to the first embodiment of the present invention.

Figs.4A to 4F are cross sectional views explaining a method of manufacturing an integrated optical device according to a second embodiment of the present invention.

Fig.5 is a perspective view of an integrated optical device according to a third embodiment of the present invention.

Fig.6 is a perspective view of an integrated optical device according to a fourth embodiment of the present invention.

Figs.7A and 7B are perspective views of rectangular optical members used by an integrated optical device according to a fifth embodiment of the present invention.

Fig.8 is a cross sectional view of a rectangular optical member used by an integrated optical device according to a sixth embodiment of the present invention.

Fig.9 is a perspective view of a conventional integrated optical device.

Figs.10A to 10F are perspective views explaining conventional methods of forming a V groove and an optical waveguide.

Fig.11 is a perspective view of a conventional integrated optical device.

Fig.12 is a perspective view of another conventional integrated optical device.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The first embodiment of the invention will be described with reference to Figs.1 to 4G.

Fig.1 is a perspective view of an integrated optical device of the first embodiment, and Figs.2A and 2B are cross sectional views of the device shown in Fig.1. Fig.2B is a cross sectional view taken along line IIB-IIB of Fig.2A.

Optical waveguides 20 are formed partially on the surface of a silicon substrate 1 having the (1 0 0) plane, with an SiO<sub>2</sub> film 14 being interposed therebetween. The SiO<sub>2</sub> film 14 is used for a planarizing layer. The optical waveguide 20 is constructed of a lower cladding layer 2, an upper cladding layer 3, and a core region 4 surrounded by the cladding layers 2 and 3. For example, the cladding layers are made of SiO<sub>2</sub> and the core region is made of a Ge doped SiO<sub>2</sub>.

A V groove 5 is formed on the surface of the silicon substrate, extending in one direction along the optical axis from the one end of the waveguide 20 which corresponds to a light input/output port. An optical fiber 9 is fitted in, and fixed to, the V groove 5 to provide a position alignment between

the optical fiber 9 and the optical waveguide 20.

A sphere lens 10, a rectangular optical member 12, a sphere lens 11, and an optical semiconductor device 8 are disposed in this order along the optical axis from the other end of the waveguide 20. The optical semiconductor device 8 is flip-chip bonded on the layer 20a which corresponds to bonding pedestal. The waveguide 20 and the bonding pedestal 20a are formed coincidentally and are formed by the same processes.

The active region of the optical semiconductor device 8 is therefore at the position higher than the core region 4. For the optical coupling between the optical fiber 9 and the optical semiconductor device 8, it is therefore necessary to displace the optical axis by a difference of the heights. From this reason, the sphere lens 10, rectangular optical member 12, and sphere lens 11 are provided.

To align the positions of the sphere lenses 10 and 11, V grooves 6 and 7 for guiding the lenses are formed on the surface of the silicon substrate 1. The lens guiding V grooves 6 and 7 may be of an up-side-down truncated pyramid shape as shown in Fig.1, or of an up-side-down pyramid shape as shown in Fig.2A. The lengths of sides of the pyramid are determined so as to make the optical axis pass through the center of the sphere lenses 10 and 11 which are fitted in the V grooves.

The rectangular optical member 12 is disposed so that the light incident and output planes of the optical member 12 are tilted by a predetermined angle relative to the optical axis so as to shift the optical axis by a desired height. A guide groove 13 is formed on the surface of the silicon substrate 1 for positioning the rectangular optical member 12.

The width and depth of the guide groove 13 are determined from the thickness of the rectangular optical member 12 so that the optical member 12 inserted into the guide groove 13 can incline by a desired angle.

The thickness of the silicon substrate is about 1 mm, the diameter of the optical fiber 9 is 125  $\mu$ m, the diameters of the sphere lenses 10 and 11 are 0.8 mm, the height of the optical axis of the semiconductor laser 8 from the surface of the bonding pedestal 20a is 6  $\mu$ m, the thickness of the SiO<sub>2</sub> film 14 is 2  $\mu$ m, the total thickness of the optical waveguide 20 and bonding pedestal 20a are 28  $\mu$ m, and the height of the core 4 of the optical waveguide from the surface of the silicon substrate 1 is 20  $\mu$ m.

Figs.3A to 3J are cross sectional views explaining a method of manufacturing an integrated optical device according to the first embodiment.

As shown in Fig.3A, an SiO<sub>2</sub> film 12 is formed on the surface of a silicon substrate 1 having the (1 0 0) plane and a thickness of 1 mm. Openings are formed in the SiO<sub>2</sub> film 15 at the positions where a

V groove 5 and lens guiding grooves 6 and 7 are formed. By using the SiO<sub>2</sub> film as a mask, the silicon substrate is selectively etched by potassium hydroxide (KOH) aqueous solution.

The KOH aqueous solution is anisotropic etchant having a very low etching speed in the (1 1 1) plane so that the (1 1 1) plane appears on the side walls of the etched grooves. After the silicon substrate 1 has been etched, the SiO<sub>2</sub> film 15 used as the mask is removed.

In this process, a thin SiO<sub>2</sub> film 15 less than 2 μm can be used as the etching mask for the V groove 5 and lens guiding V grooves 6 and 7, allowing the V grooves to be etched precisely.

In conventional process, a SiO<sub>2</sub> film as thick as above 3 μm is used as the etching mask, because of KOH aqueous solution slightly corrodes SiO<sub>2</sub> and residual SiO<sub>2</sub> film must be used as isolator for wiring patterns on the surface.

As shown in Fig.3B, a silicon substrate 16 is prepared which is formed with an SiO<sub>2</sub> film 14 on the surface of the silicon substrate, the SiO<sub>2</sub> film having a thickness of 2 μm. This silicon substrate 16 is bonded to the silicon substrate 1 formed at the process of Fig.3A, by directing the surface with the V grooves of the silicon substrate 1 to the surface with the SiO<sub>2</sub> film of the silicon substrate 16. This bonding may be performed by using chemical bonding between molecules. For example, both the substrates can be bonded together by heating them placed one upon the other at 1000 °C for about one hour. A voltage may be applied between the silicon substrates to assist their bonding.

As shown in Fig.3C, after both the substrates are bonded together, the silicon substrate 16 is removed by grinding/or polishing and etching. The substrate 1 of a two-layer structure can thus be obtained, covering the openings of the V groove 5 and lens guiding V grooves 6 and 7 with the SiO<sub>2</sub> film which acts as a planarizing layer.

As shown in Fig.3D, a layer for lower cladding layer 2, a core region 4, and upper cladding layer 3 are deposited on the SiO<sub>2</sub> film 14. The layer for core region 4 is patterned by photoetching to form the core region. Since the V groove 5 and lens guiding V grooves 6 and 7 are covered with the planarizing layer of SiO<sub>2</sub> film 14, materials of the optical waveguide components will not enter the V grooves.

As shown in Fig.3E, bonding pads 17 for bonding an optical semiconductor device 8 are formed on the layer for cladding layer 3 at predetermined positions. Next, a mask 18 is formed covering the bonding pads 17 and the regions where optical waveguide 20 and bonding pedestal 20a are formed.

As shown in Fig.3F, after the mask 18 has been formed, an unnecessary region of the deposited layer 20b formed by the layer for cladding layers 2 and 3 and core region and an unnecessary region of the SiO<sub>2</sub> film 14 are etched to expose the V groove 5 and lens guiding V grooves 6 and 7. An amorphous silicon mask and a reactive-ion-beam-etching technique may be used for the processes respectively.

As shown in Fig.3G, the mask 18 is removed to expose the bonding pads 17. Next, a rectangular guide groove 13 is formed by using a dicing saw. Next, as shown in Fig.3H, the optical semiconductor device 8 having bonding pads is flip-chip bonded to the bonding pads 17.

In Figs.3A to 3G, the SiO<sub>2</sub> film 14 and optical waveguide 20 are shown thicker than the actual dimension for the easy understanding of the description. In Fig.3H, however, the SiO<sub>2</sub> film and optical waveguide 20 are shown thinner matching the actual scale.

Next, as shown in Fig.3I, the sphere lenses 10 and 11 and rectangular optical member 12 are fitted in the lens guiding V grooves 6 and 7 and V groove 13, respectively.

As shown in Fig.4J, a metal film 19 may be formed on the surface of the cladding layer 3 to enhance heat dissipation. A laminated thin optical isolator may be used as the rectangular optical member 12.

According to the first embodiment, face-down flip-chip bonding is used for bonding the optical semiconductor device 8 so that position alignment of a relatively high precision can be obtained even if the outer dimension of the optical semiconductor device is different from the original design. The integrated optical device manufactured by the embodiment method has a displacement of 2 μm or less from a target position of the optical semiconductor device.

The positions and pattern of the bonding pads 17 are precise because they are formed on a flat surface as shown at the process of Fig.3E.

The second embodiment of the invention will be described with reference to Figs.4A to 4F. The second embodiment is characterized by a use of a silicon layer in place of the SiO<sub>2</sub> film of the first embodiment, and the other structures are the same as the first embodiment.

Figs.4A to 4F illustrate the steps of manufacturing an integrated optical device according to the second embodiment of the invention. Similar elements to those shown in Figs.3A to 3J are represented by using identical reference numerals.

As shown in Fig.4A, a silicon substrate 1 is prepared which has a V groove 5 and lens guiding V grooves 6 and 7 formed in the manner like the process of Fig.3A. This silicon substrate 1 is bon-

ded to another silicon substrate 16, by directing the surface with the V grooves of the silicon substrate 1 to the surface of the silicon substrate 16. As shown in Fig.4B, the silicon substrate 16 is ground and polished to leave the silicon layer having a thickness of 50  $\mu\text{m}$ . In this manner, a substrate of a two-layer structure is obtained wherein the  $\text{SiO}_2$  film 14, which serves as an planarizing layer, at the process of Fig.3C of the first embodiment is replaced by the silicon layer 16, which serves as an planarizing layer too.

Next, as shown in Fig.4C, in the manner like the processes shown in Figs.3D and 3E of the first embodiment, a layer for optical waveguide 20b, bonding pads 17, and a mask 18 are formed on the silicon layer 16. The layer for optical waveguide 20b is formed by two clad layers and core sandwiched therebetween. In Figs.4C to 4E, the layer for optical waveguide 20b is shown as having a single layer.

As shown in Fig.4D, the exposed silicon layer 16 is etched out. If a KOH aqueous solution is used as etchant, the surfaces of the V groove 5 and lens guiding V grooves are scarcely etched.

Thereafter, processes similar to the processes of Figs.3G to 3I are performed to form an integrated optical device having the silicon layer 16 in place of the  $\text{SiO}_2$  film of the first embodiment.

In the second embodiment, when the unnecessary region of the layer 20b is etched to leave necessary region for optical waveguides 20 and bonding pedestal 20a, the silicon layer 16 functions as an etching stop layer, thereby improving the etching controllability.

Furthermore, since a thick silicon layer is easy to form as compared to an  $\text{SiO}_2$  film, the height of the optical axis from the surface of the silicon substrate 1 can be made greater. As a result, the diameter of a light beam can be made large and the optical coupling tolerance can be improved.

As the silicon substrate 16, a single crystal silicon substrate as well as an amorphous silicon substrate can be used. As shown in the side view of Fig.4F and the cross section of Fig.4G, the silicon layer 16 may be left between the  $\text{SiO}_2$  film 14 and optical waveguide 16 of the first embodiment.

Next, the third embodiment of the invention will be described with reference to Fig.5.

Fig.5 shows an integrated optical device of the third embodiment. The optical waveguide of the integrated optical device shown in Fig.5 has five core regions 4a to 4e and one core region 4 which constitute an optical multiplexer. Semiconductor lasers 8a to 8e having different oscillation wavelengths are used as optical semiconductor devices to constitute a light source for multiple wavelength optical communications.

Laser beams radiated from the semiconductor lasers 8a to 8e pass through sphere lenses 11a to 11e and become incident onto a rectangular optical member 12. The optical axes of the laser beams are shifted down by the rectangular optical member 12, and the beams pass through sphere lenses 10a to 10e and become incident onto the core regions 4a to 4c.

The sphere lenses 10a to 10e, and 11a to 11e are aligned at predetermined positions (in-plane positions and heights) by lens guiding V grooves 6a to 6e, and 7a to 7e., and fixed thereto. In the manner similar to the first embodiment shown in Fig.1, the rectangular optical member 12 is inclined by a predetermined angle relative to the optical axis by a guide groove 13, and fixed thereto.

The laser beams incident onto the core regions 4a to 4e are converged to the core regions 4 and become incident onto an optical fiber 9 fixed by the V groove 5.

As described above, an optical multiplexer is formed by a multiplicity of optical semiconductor devices and spherical lenses and optical waveguides. A light source for multiple wavelength optical communications can thus be manufactured without any adjustment. By using the similar structure, an integrated optical device having an optical demultiplexer (wave-dividing) function may be formed.

Next, the fourth embodiment of the invention will be described with reference to Fig.6.

Fig.6 shows an integrated optical device of the fourth embodiment. In the integrated optical device shown in Fig.6, the optical waveguide is used as a pitch changing means for changing a 1000  $\mu\text{m}$  pitch suitable for sphere lenses to a 250  $\mu\text{m}$  pitch suitable for optical fibers. This integrated optical device forms a 5-channel parallel light source having five semiconductor lasers optically coupled to ribbon fibers having a pitch of 250  $\mu\text{m}$  via an optical waveguide having a pitch convertor.

The structures of semiconductor lasers 8a to 8e and core regions 4a to 4e are the same as those of the third embodiment shown in Fig.3 except for each core regions being separated. The semiconductor lasers 8a to 8e, sphere lenses 11a to 11e, and 10a to 10e, and the core regions 4a to 4e on the sphere lens side, are all disposed at the pitch of 1000  $\mu\text{m}$ . The pitch of the core regions 4a to 4e are made narrower toward the optical fiber side, and is set to 250  $\mu\text{m}$  on the side of the ends of the optical fibers.

Laser beams radiated from the semiconductor lasers 8a to 8e are made to have a narrowed pitch of 250  $\mu\text{m}$ , and are incident onto ribbon fibers 9a to 9e aligned at a pitch of 250  $\mu\text{m}$  by V grooves 5a to 5e.



In this manner, a parallel light source can be formed without any adjustment by providing a plurality of optical semiconductor devices, sphere lenses, and optical fibers. The pitch change by the optical waveguide reduces inter-channel crosstalk at the electric circuit stage, compared to the case of coupling optical fibers and optical semiconductor devices at a pitch of 250  $\mu\text{m}$ .

In the third and fourth embodiments, a semiconductor laser has been used as the optical semiconductor device. If a semiconductor laser is replaced by a photodiode, a light reception device can be realized.

Next, the fifth embodiment of the invention will be described with reference to Figs.7A and 7B.

Fig.7A shows a rectangular optical member 12 of the fifth embodiment. The rectangular optical member shown in Fig.7A has a structure that a high refractive index rectangular glass plate 12b are sandwiched between two low refractive index glass plates 12a and 12c.

A laser beam incident onto the incident plane of, for example, the low refractive index plate 12a refracts at the interface between the low refractive index glass plate 12a and the high refractive index glass plate 12b and at the interface between the high refractive index glass plate 12b and the low refractive index glass plate 12c, resulting in a optical axis shift. The same effect as the rectangular optical members 12 of the first to fourth embodiments can therefore be obtained. In this embodiment, it may be acceptable that the glass plates 12a and 12c have higher refractive index and glass plate 12b is inclined oppositely.

The rectangular optical member 12 of this embodiment can be fitted in the guide groove 13 without any gap, thereby improving a mount precision thereof.

As shown in Fig.7B, laser beam pass holes 21 may be formed in glass plates 12d and 12f at the positions where a laser beam passes. With this structure, it is possible to use glass plates 12d, 12e, and 12f having the same refractive index. Furthermore, instead of the glass plates 12d and 12f, articles made of opaque material may be used.

The sixth embodiment will be described with reference to Fig.8 which shows a cross section of a rectangular optical member 12g cut along the plane of an optical axis 26 of the optical system. The rectangular plate optical member 12g uses rutile crystal which is a material having birefringence.

Use of a material having birefringence allows the optical axis to be shifted even if the light incident and output planes are disposed perpendicular to the optical axis of incident light beam.

It is therefore possible to shift the optical axis simply by disposing even a relatively thin crystal

perpendicularly to the optical axis. Similar to the fifth embodiment, this rectangular optical member can be fitted in a guide groove without any gap, so that a mount precision can be improved.

In this embodiment, rutile crystal has been used as a material having birefringence. Other birefringence materials such as calcite may also be used.

In the first to sixth embodiments, various types of known materials may be used for an optical waveguide. For example, such materials include organic polymer, dielectric material, amorphous semiconductor, films such as an oxidized silicon film and a film of silicon-nitride formed on semiconductor.

The bonded substrate shown, for example, in Fig.3C is resistant against a high temperature of about 1400  $^{\circ}\text{C}$  so that it can be used for forming a  $\text{GeO}_2$  -  $\text{SiO}_2$  based optical waveguide which is formed under a high temperature.

The techniques disclosed in the applications by the present inventor (Japanese Patent Application No.5-65559 filed on March 24, 1993, USSN 08/186,027 filed on January 25, 1994, Germany Patent Application P 4402422.3 filed on January 27, 1994) may be used with the above embodiments, which are herein incorporated by reference.

The present invention has been described in connection with the preferred embodiments. The invention is not limited only to the above embodiments. It is apparent to those skilled in the art that various modifications, improvements, combinations and the like can be made without departing from the scope of the appended claims.

## Claims

1. An integrated optical device comprising:
  - a silicon substrate (1) having a surface;
  - a planar optical waveguide (20) which is formed partially on said silicon substrate (1), and has a light guiding core region (4) of high refractive index surrounded by a lower-index cladding layer (2,3) and a flat top surface;
  - a bonding pedestal (20a) which is formed partially on said silicon substrate occupying a portion different from the portion occupying said planar optical waveguide and has a flat top surface, the heights of said top flat surface of said bonding pedestal (20a) and said planar optical waveguide (20) from the surface of said silicon substrate being the same;
  - an edge input/output type optical semiconductor device (8) bonded on said top flat surface of said bonding pedestal (20a), said edge input/output type optical semiconductor device being mounted on an imaginary line extending from a light input/output end of said planar

optical waveguide so that said edge input/output type optical semiconductor device align with said planar optical waveguide, levels of the optical axes of said planar optical waveguide and said edge input/output type optical semiconductor device from the surface of said silicon substrate being different; and

means for changing level of an optical axis (10,11,12) for optically coupling said planar optical waveguide and said edge input/output type optical semiconductor device through changing height of optical axis relative to the surface of said silicon substrate.

2. An integrated optical device according to claim 1, further comprising:

a V groove (5) having a V-shaped cross section for position-aligning an optical fiber, and being formed on the surface of said silicon substrate along an optical axis extending in one direction from other input/output end of said planar optical waveguide (20); and

an optical fiber (9) which is fitted in, and fixed to, said V groove (5) to provide a position alignment between said optical fiber (9) and said planar optical waveguide (20).

3. An integrated optical device according to claim 1 or 2, wherein said level changing means comprises an optical member (12) which is composed of a transparent plate (12) having parallel, opposite planes of light incident and output planes, normal direction of said light incident and output planes of said transparent plate (12) being disposed to be inclined by a predetermined angle from the optical axis of an incident light beam so as to refract said incident light beam and shift up or down level of said incident light beam.

4. An integrated optical device according to Claim 1 or 2, wherein said level changing means comprises an optical member (12) which includes:

a transparent plate (12b) having parallel, opposite planes of light incident and output planes, normal direction of said light incident and output planes of said transparent plate (12b) being disposed to be inclined by a predetermined angle from the optical axis of an incident light beam so as to refract said incident light beam and shift up or down level of said incident light beam; and

two transparent members (12a, 12c) having reflective index different from said transparent plate (12b) and wedge-shaped cross section, and sandwiching said transparent plate (12b) in such a manner that one planes of said

two transparent members (12a,12c) are disposed perpendicular to an optical axis, and the other planes are disposed in tight contact with the light incident and output planes of said transparent plate (12b).

5. An integrated optical device according to Claim 1 or 2, wherein said level changing means comprises an optical member (12) which includes:

a transparent plate (12e) having parallel, opposite planes of light incident and output planes, normal direction of said light incident and output planes of said transparent plate being disposed to be inclined by a predetermined angle from the optical axis of an incident light beam so as to refract said incident light beam and shift up or down level of said incident light beam; and

two support members (12f, 12g) having registered through holes and wedge-shaped cross section, and sandwiching said transparent plate (12e) in such a manner that one planes of said two support members (12f,12g) are disposed perpendicular to an optical axis and the other planes are disposed in tight contact with the light incident and output planes of said transparent plate, and said registered through holes of said two support members is located at a region where a light beam transmits.

6. An integrated optical device according to Claim 1 or 2, wherein said level changing means comprises:

an optical member (12) which is composed of a transparent, birefringent plate (12g) formed of a birefringent crystal and having parallel, opposite planes of light incident and output planes, said light incident and output planes being disposed perpendicularly to the optical axis of an incident light beam;

said light incident and output planes of said transparent, birefringent plate being inclined from an optic axis of the birefringent crystal composing said transparent, birefringent plate so that said transparent, birefringent plate refract said incident light beam and moved up or down said incident light beam whereby said incident light beam is polarized rectilinear.

7. An integrated optical device according to any one of Claims 3 to 6, further comprising an optical member guide groove (13) formed on the surface of said silicon substrate (1) for position-aligning said optical member (12) on the surface of said silicon substrate.

8. An integrated optical device according to Claim 7, wherein said optical axis changing means further includes:
- a first lens (11) for collimating a light beam emitted from said edge input/output type optical semiconductor device or converging a collimated light beam into said edge input/output type optical semiconductor device;
  - a first lens guide hole (7) formed on the surface of said silicon substrate for position-aligning said first lens on the surface of said silicon substrate;
  - a second lens (10) for converging a collimated light beam into said optical planar waveguide or collimating a light beam emitted from said planar optical waveguide; and
  - a second lens guide hole (6) formed on the surface of said silicon substrate for position-aligning said second lens on the surface of said silicon substrate, wherein said optical member guide groove is formed between said first and second lenses.
9. An integrated optical device according to Claims 8, further comprising a planarizing layer (14,16) formed between said clad layer and said silicon substrate.
10. An integrated optical device according to Claim 9, wherein said planarizing layer is an SiO<sub>2</sub> film.
11. An integrated optical device according to Claim 9, wherein said planarizing layer is a silicon layer.
12. An integrated optical device according to Claim 9, wherein said planarizing layer has a two-layer structure of an SiO<sub>2</sub> film and a silicon layer.
13. A method of forming an integrated optical device comprising the steps of:
- forming an optical fiber guide groove and first and second lens guiding grooves for position-aligning lenses by selectively etching the surface of a silicon substrate through anisotropic etching;
  - bonding another silicon substrate having a planarizing layer formed on the surface of said other silicon substrate to said silicon substrate, by directing said cover layer to the surface of said silicon substrate;
  - removing said other silicon substrate and leaving said planarizing layer;
  - forming a deposited layer (20b) for planar optical waveguide by depositing lower cladding layer material and material for core region on said planarizing layer, by patterning said deposited materials for core region through photolithography and by depositing upper cladding layer material;
  - forming bonding pads (17) for bonding an optical semiconductor device (8) at a place corresponding to said bonding pedestal on said top surface of said deposited layer (20b) for planar optical waveguide;
  - selectively removing said optical waveguide and said planarizing layer and exposing said V groove and said first and second lens guiding grooves; and
  - forming a optical member guide groove (13) suitable for position-aligning a optical member (12) for shifting the levels of optical axes, on the surface of said silicon substrate between said first and second lens guiding grooves.
14. A method according to claim 13, further comprising the step of position-aligning said optical member (12) at said rectangular optical member guide groove (13).
15. A method according to claim 13 or 14, wherein said planarizing layer is an SiO<sub>2</sub> layer.
16. A method according to claim 13 or 14, wherein said planarizing layer is a surface silicon layer.
17. A method according to claim 13 or 14, wherein said planarizing layer is a laminated layer of a surface silicon layer and an SiO<sub>2</sub> layer.
18. An integrated optical device comprising:
- a silicon substrate (1);
  - a planar optical waveguide (20) which is formed partially on said silicon substrate (1), and has a plurality of light guiding core regions (4a,4b,4c,4d,4e) of high refractive index surrounded by a lower-index cladding layer (2,3) and a flat top surface, said plurality of light guiding core regions having opposite light input/output ports respectively, and disposed non-parallel, and pitch of said light input/output ports on one and the other sides being constant and being different from each other;
  - a plurality of edge input/output type optical semiconductor devices (8a,8b,8c,8d,8e), being positioned in a line with the same pitch of said light input/output ports of said planar waveguide facing said edge input/output type optical semiconductor devices, said edge input/output type optical semiconductor devices being positioned on optical axes extending from said light input/output ports of said light guiding core regions so that said edge in-

put/output type optical semiconductor devices align with said light input/output ports of said light guiding core regions respectively;

a plurality of V grooves (5a,5b,5c,5d,5e) having a V-shaped cross section for position-aligning optical fibers, being formed on the surface of said silicon substrate along optical axes extending in one direction from other input/output ports of said planar optical waveguide (20) respectively, and said V grooves being arranged at a constant pitch which is smaller than that of said edge input/output semiconductor devices; and

optical fibers (9a,9b,9c,9d,9e) which are fitted in, and fixed to, said V grooves to provide a position alignment between said optical fibers and said light guiding core regions of said planar optical waveguide respectively.

19. An integrated optical device comprising:

a silicon substrate (1) having a surface;

a planar optical waveguide (20) which is formed partially on said silicon substrate (1), and has a plurality of light guiding core regions (4a,4b,4c,4d,4e) of high refractive index, a lower-index cladding layer (2,3) surrounding the core regions and having a flat top surface, said a plurality of light guiding core regions having opposite light input/output ports disposed at constant pitches respectively, the pitch of said light input/output ports on one side being different from that of said light input/output ports on the other side;

a bonding pedestal (20a) which is formed partially on said silicon substrate occupying a portion different from the portion occupying said planar optical waveguide and has a flat top surface, with heights of said top flat surfaces of said bonding pedestal (20a) and said planar optical waveguide (20) from the surface of said silicon substrate being the same;

a plurality of edge input/output type optical semiconductor devices (8a,8b,8c,8d,8e) bonded on said top surface of said bonding pedestal (20a), said edge input/output type optical semiconductor devices being mounted in a line with the same pitch as that of said light input/output ports of said planar waveguide facing the plurality of edge input/output type optical semiconductor devices, said edge input/output type optical semiconductor devices being mounted on optical axes extending from said light input/output ports of said light guiding core regions so that said edge input/output type optical semiconductor devices align with said light input/output ports of said light guiding core regions respectively, heights of optical axes of said edge input/output type optical

semiconductor devices being the same, and heights of optical axes of said light guiding core regions being the same, and heights of said optical axes of said edge input/output type optical semiconductor devices and said light guiding core regions being different;

means for changing level of optical axis (10,11,12) for optically coupling said light guiding core regions of said planar optical waveguide and said optical semiconductor devices through changing the heights of optical axes relative to the surface of said silicon substrate at each said edge input/output type optical semiconductor device and said light guiding core regions of said planar optical waveguide; and

a plurality of V grooves (5a,5b,5c,5d,5e) having a V-shaped cross section for position-aligning optical fibers, being formed on the surface of said silicon substrate along optical axes extending in one direction from other input/output ports of said planar optical waveguide (20) respectively, and said V grooves being arranged at a constant pitch which is smaller than that of said edge input/output semiconductor devices; and

optical fibers (9a,9b,9c,9d,9e) which are fitted in, and fixed to, said V grooves to provide a position alignment between said optical fibers and said light guiding core regions of said planar optical waveguide respectively.

FIG.1

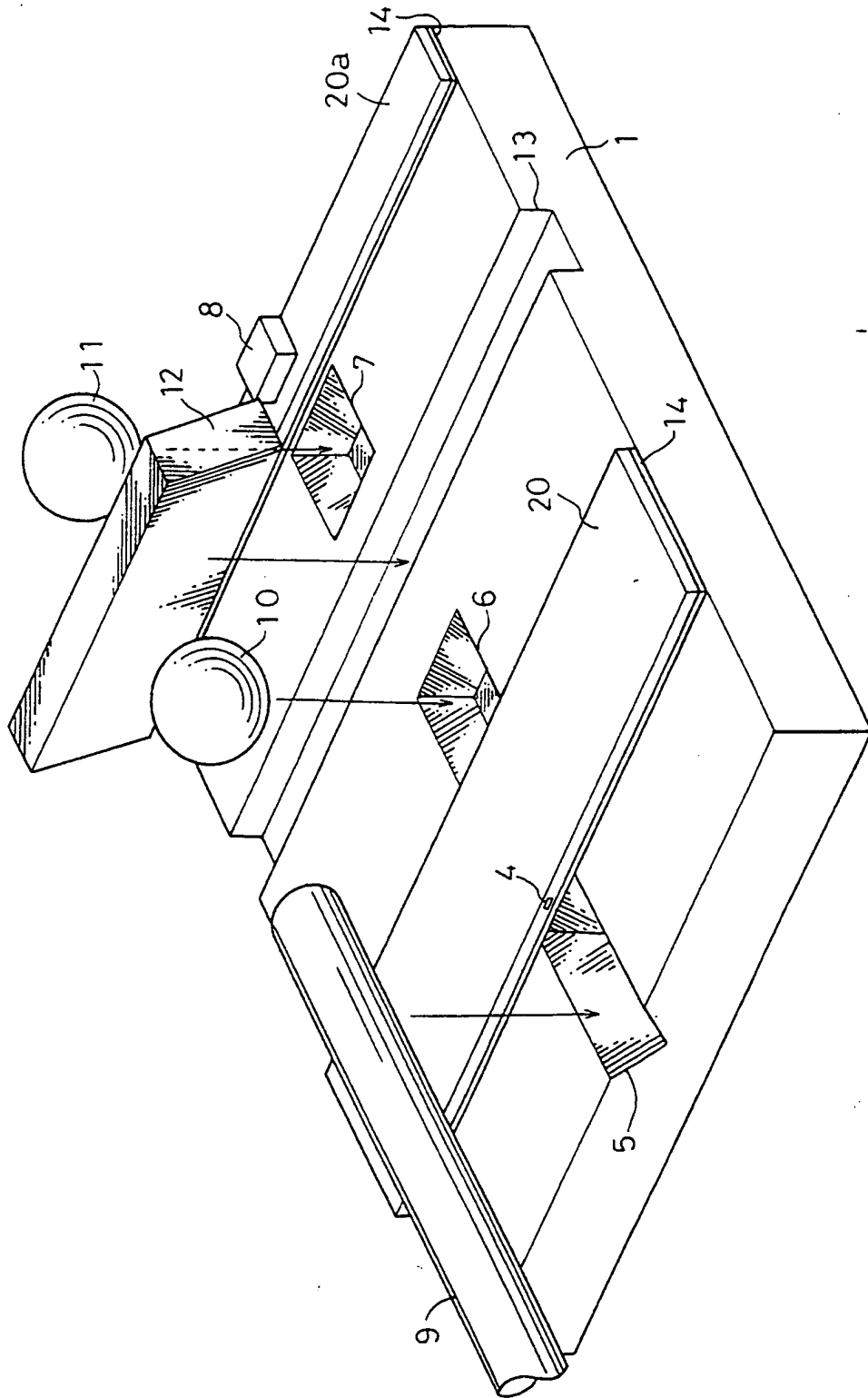


FIG. 2A

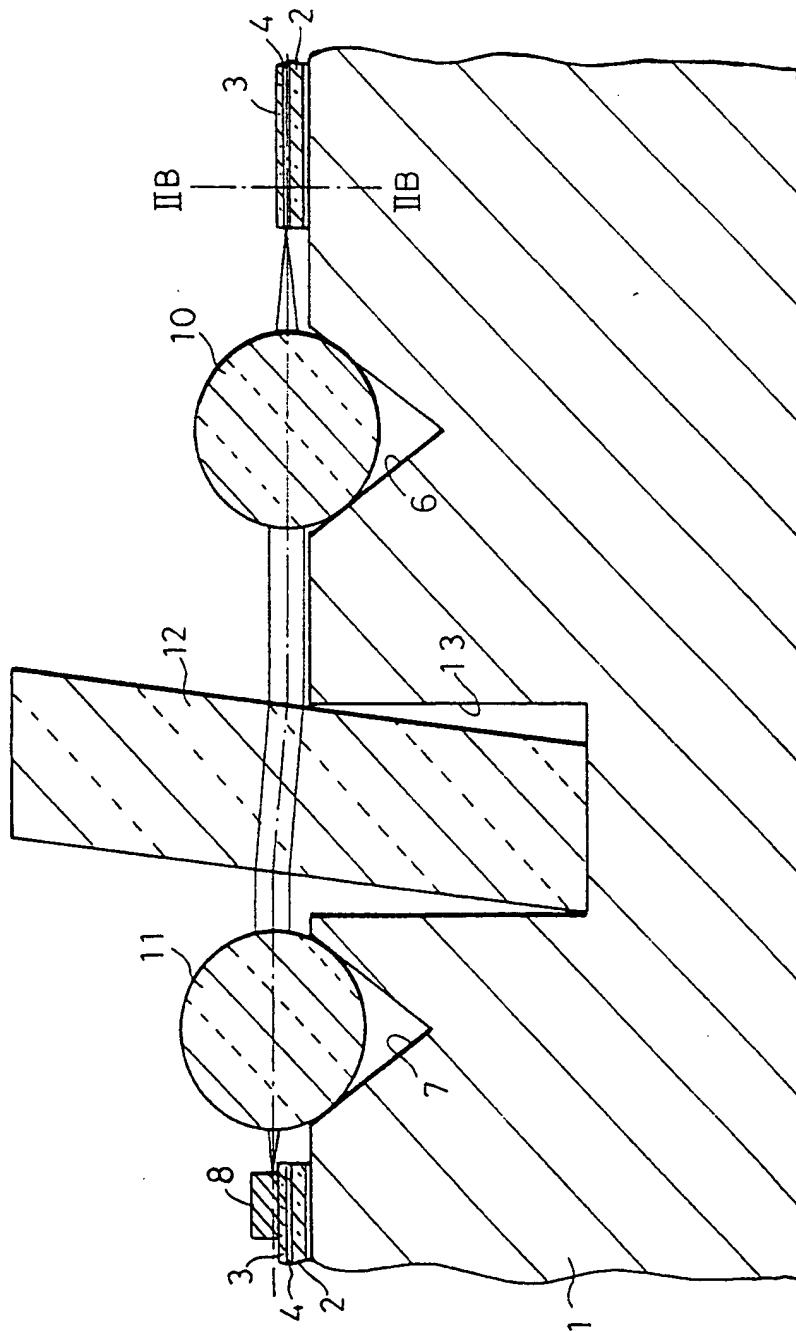


FIG. 2B

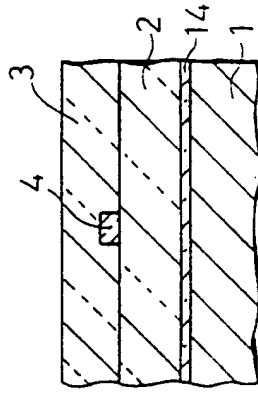


FIG. 3A

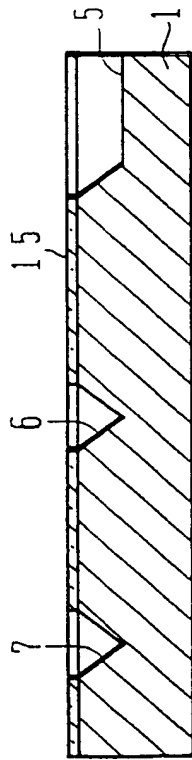


FIG. 3B

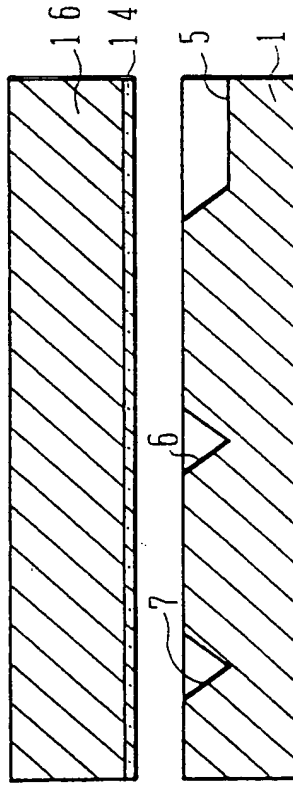


FIG. 3C

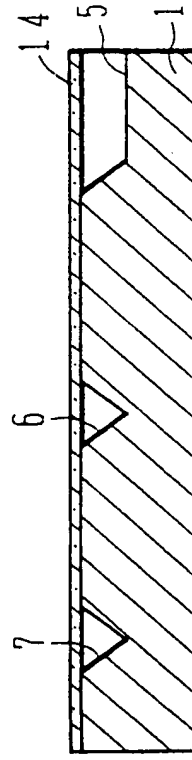


FIG. 3D

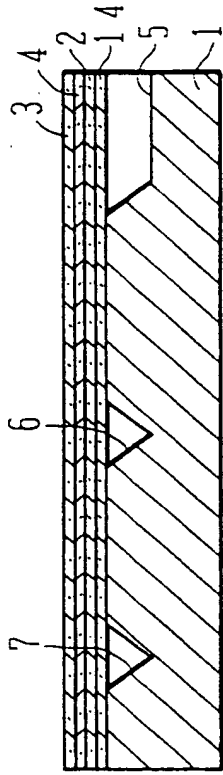


FIG. 3E

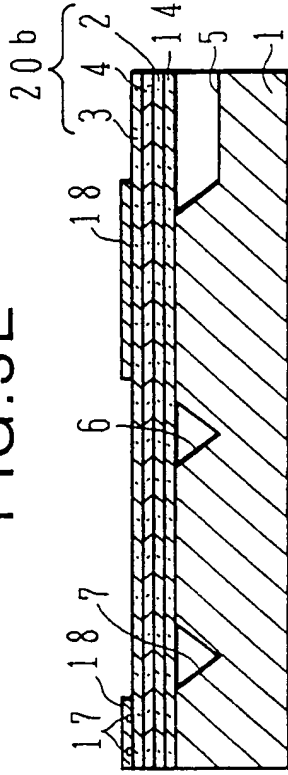


FIG. 3F

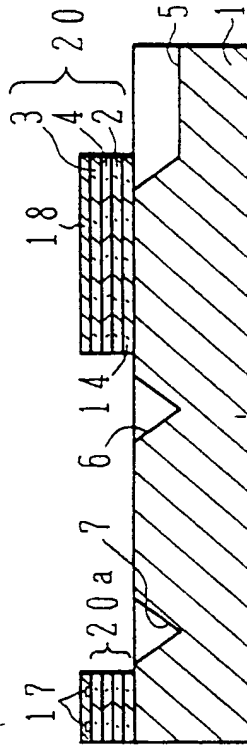


FIG. 3G

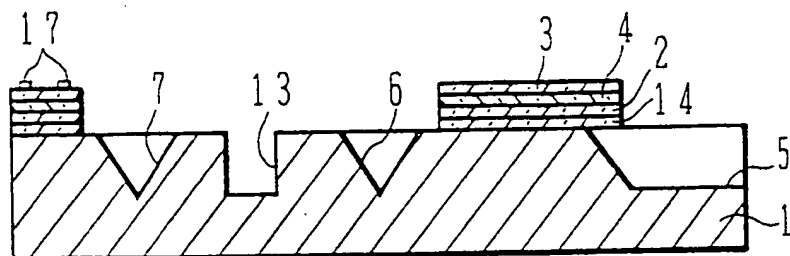


FIG. 3H

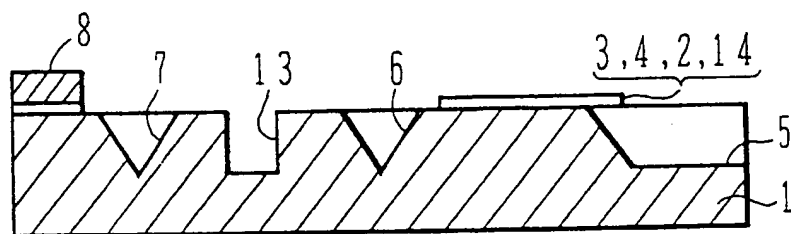


FIG. 3I

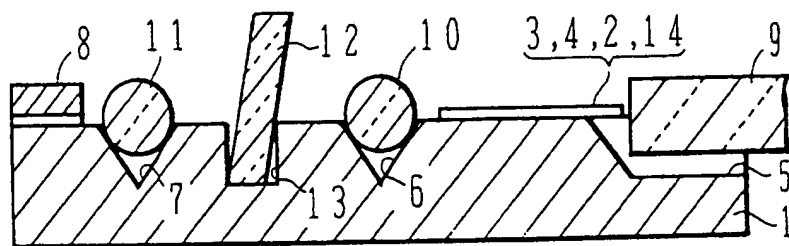


FIG. 3J

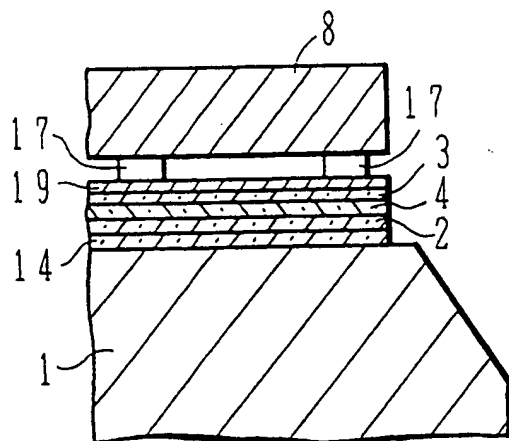
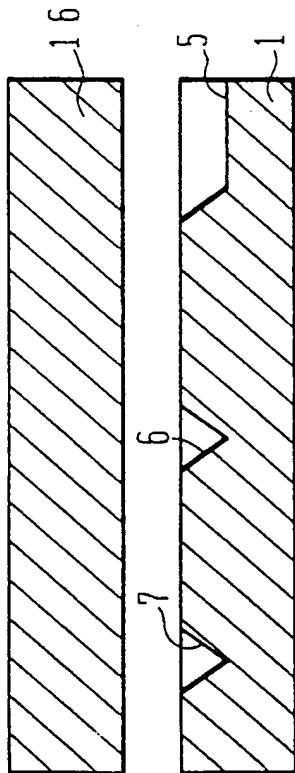




FIG. 4A



**FIG. 4B**

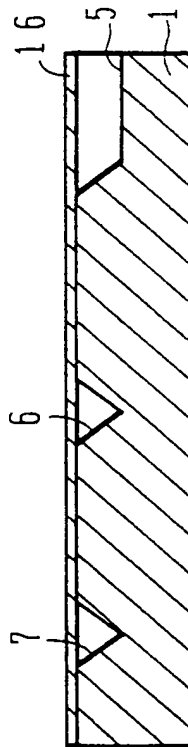


FIG. 4C

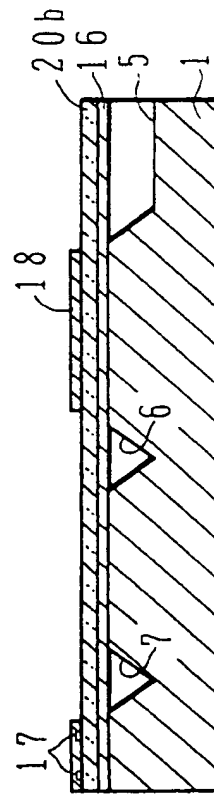


FIG. 4D

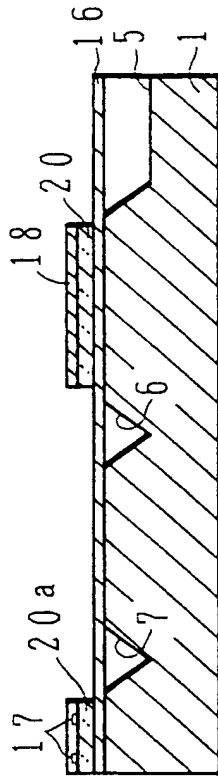


FIG. 4E

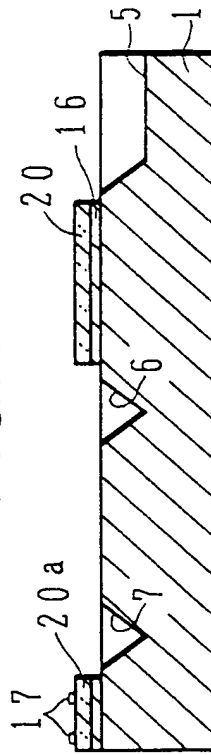


FIG. 4F

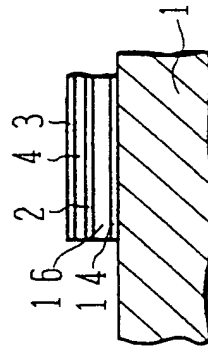


FIG. 4G

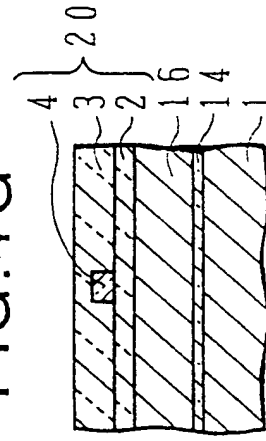


FIG. 5

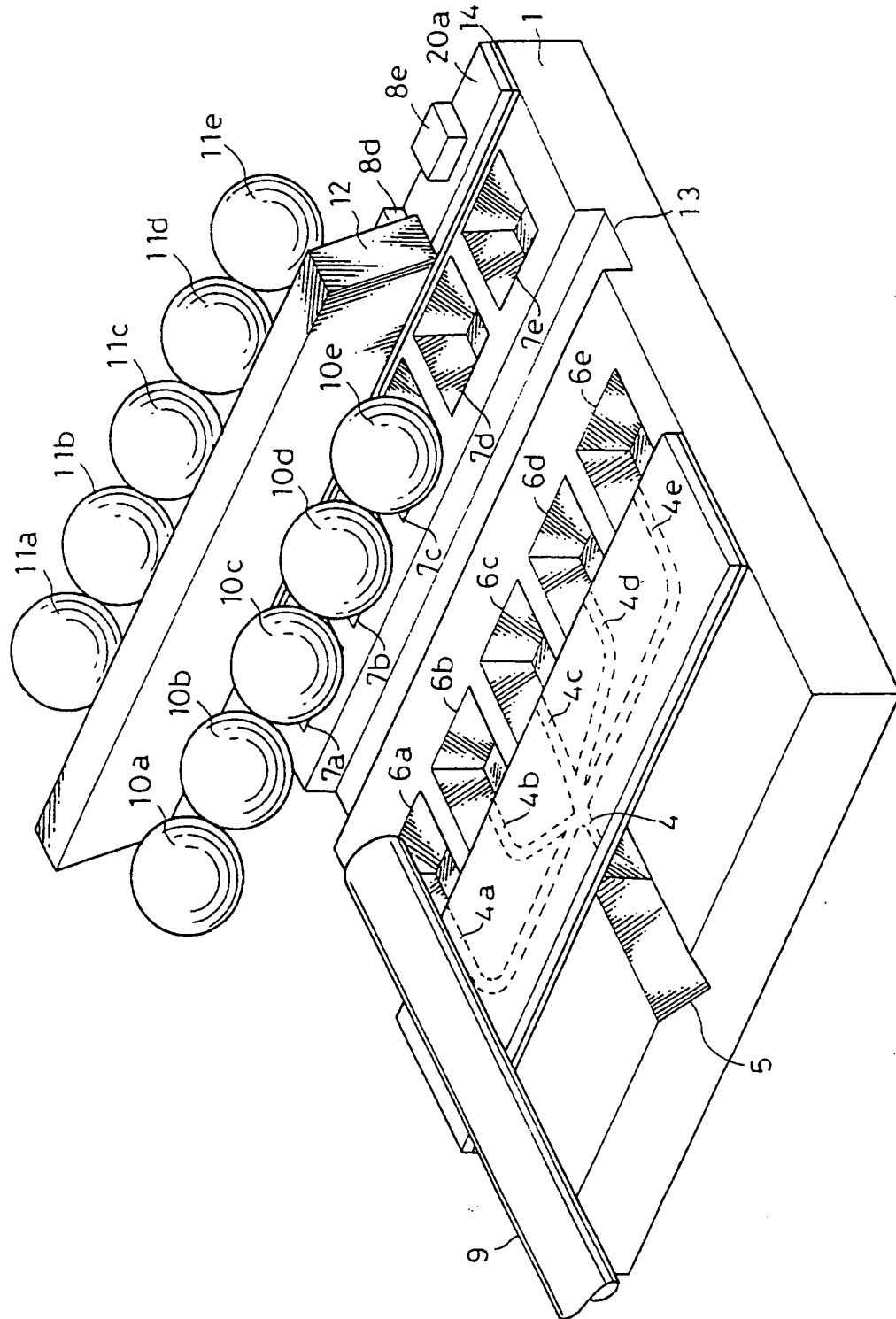


FIG. 6

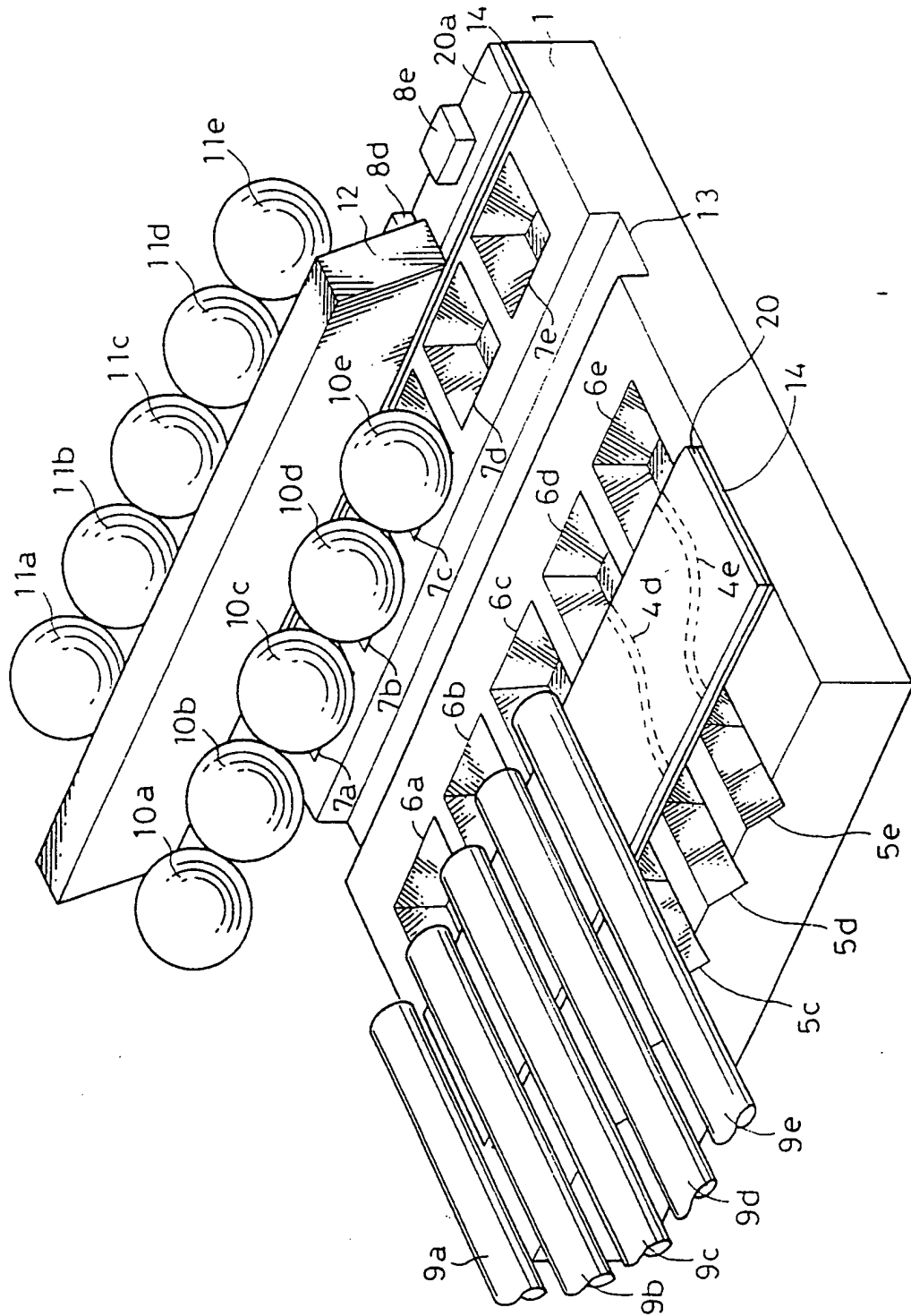


FIG.7A

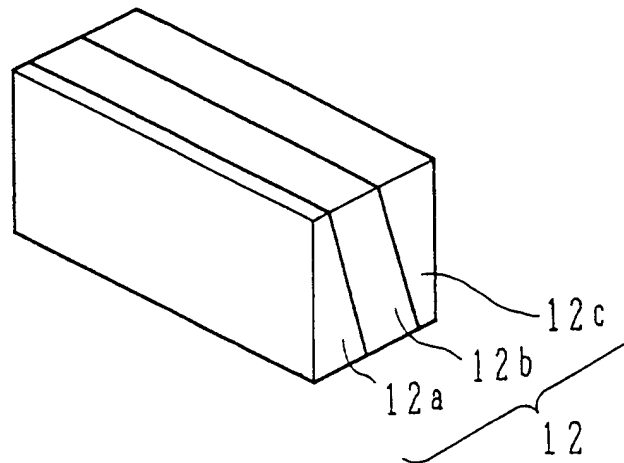


FIG.7B

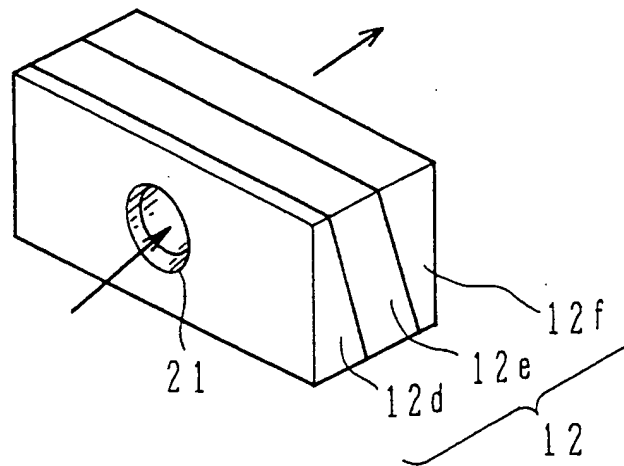


FIG.8

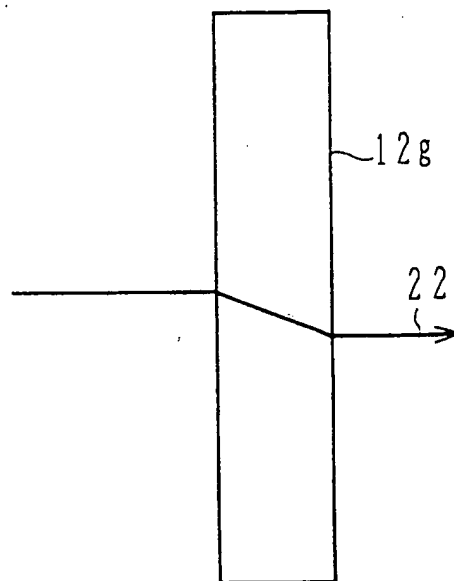


FIG.9  
(PRIOR ART)

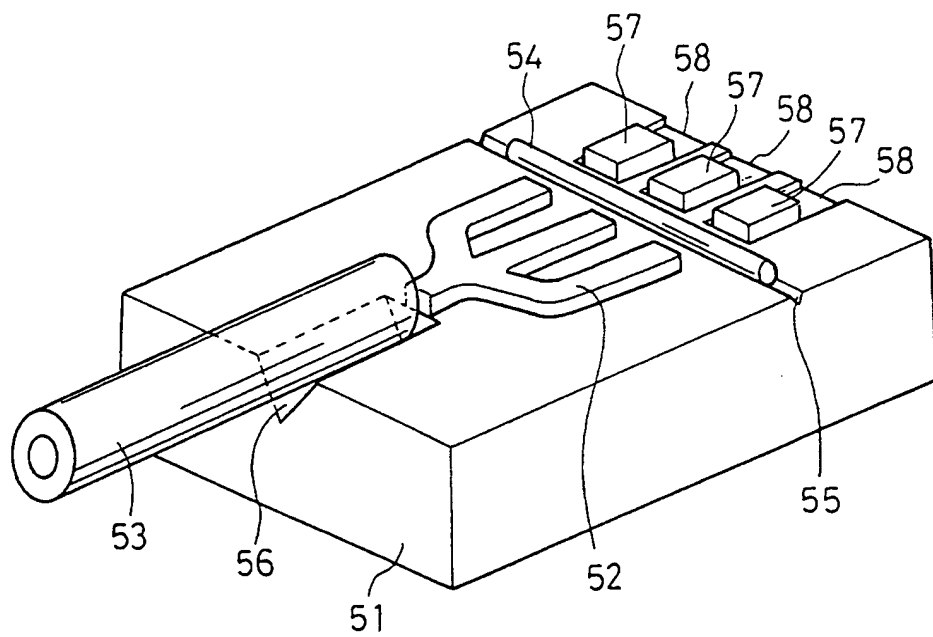


FIG.10A  
(PRIOR ART)

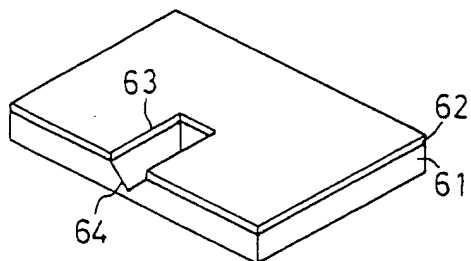


FIG.10D  
(PRIOR ART)

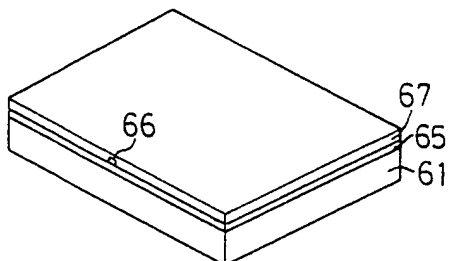


FIG.10B  
(PRIOR ART)

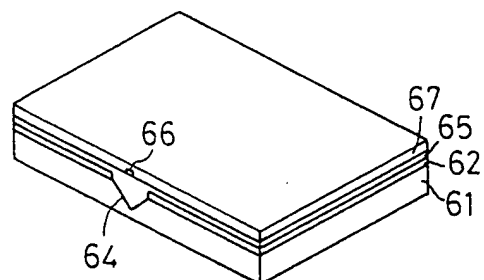


FIG.10E  
(PRIOR ART)

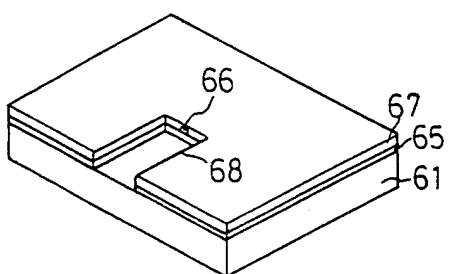


FIG.10C  
(PRIOR ART)

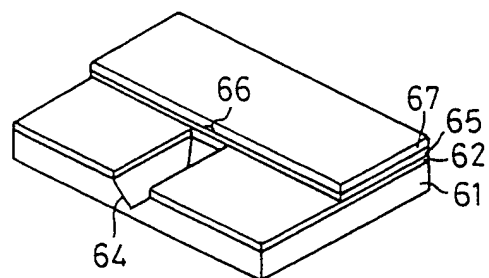


FIG.10F  
(PRIOR ART)

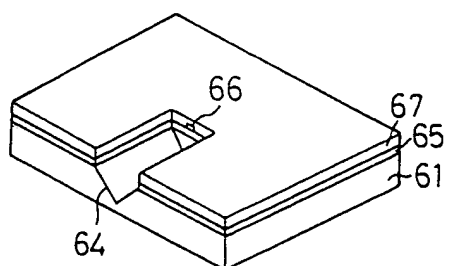


FIG.11  
(PRIOR ART)

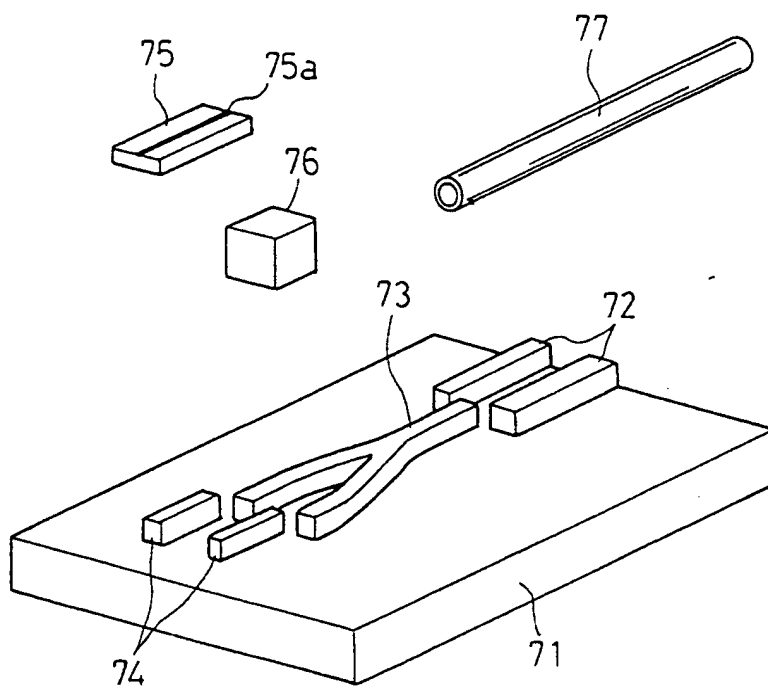
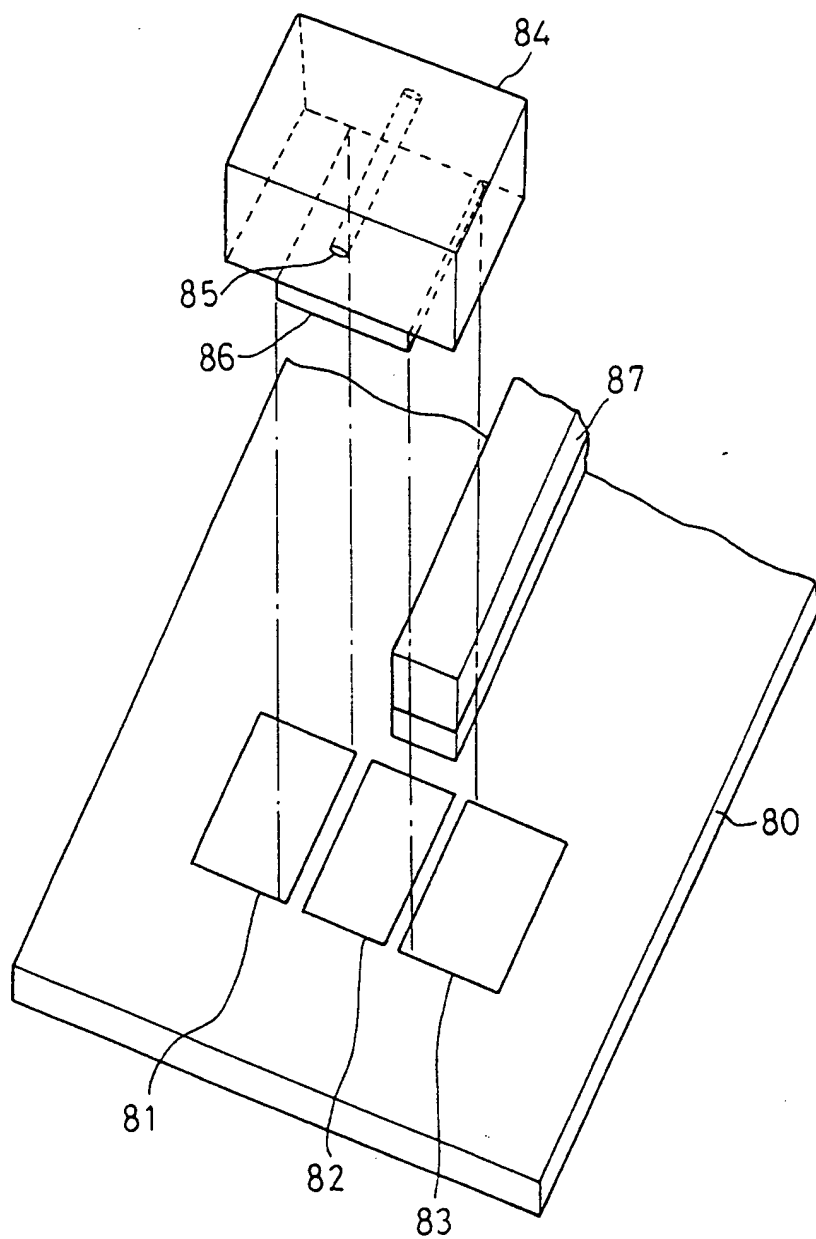


FIG.12  
(PRIOR ART)







European Patent  
Office

## EUROPEAN SEARCH REPORT

Application Number  
EP 94 10 8254

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	DE-A-37 31 311 (SIEMENS)  * column 2, line 66 - column 3, line 31 * * figure 1 *  ---	1,2,13, 19	G02B6/42
A	EP-A-0 331 338 (AT&T)  * column 3, line 16 - line 47 * * column 5, line 39 - line 55 * * figures 1,8 *  ---	1,2,13, 14	
A	LEOS '90, Boston, Massachusetts, 4-9 november 1990, Proceedings vol. 2, IEEE, New York, G.E. Blonder: 'Silicon Optical Bench Research at AT&T Bell Laboratories', page 350-353 * page 351 *  ---	13	
A	DE-A-40 13 630 (SIEMENS) * column 1, line 62 - line 66 * * column 2, line 30 - line 43 * * figure 2 *  ---	13	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	WO-A-92 00538 (BRITISH TELECOMMUNICATIONS) * page 12, line 37 - page 13, line 21 * * figure 10 *  -----	18,19	G02B
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>19 December 1994</b>	Examiner <b>Luck, W</b>
<b>CATEGORY OF CITED DOCUMENTS</b>			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- A : member of the same patent family, corresponding document			